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FINAL REPORT

REPLICATOR FOR CHARACTERIZATION OF CIRRUS AND POLAR STRATOSPHERIC CLOUD PARTICLES

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ABSTRACT

A formvar replicator for installation in an aircraft pod has been designed, built, and flight tested on the NASA DC-8. The system incorporates a deicing capability (which can be pressure activated) to enable climb out through icing situations prior to deployment. The system can be operated at preselected speeds such that data can be recorded over a period of 1 to ten hours on 200 ft of 16mm film. A x2 speed control can be used during flight. Capability exists for detection of chemical constituents by appropriate doping of the formvar solution.

1. Introduction: The Continuous Formvar Replicator

The concept of the continuous formvar was described by MacCready and Todd (1964). A thin layer of formvar resin in chloroform solution is applied to a 16 mm film which is drawn past a slot (2.5 mm wide x 7.5 high mm high) exposed to the air stream. Particles carried in the air stream cross the streamlines, pass through the slot and are collected on the film. As the film dries, a detailed cast of the original water drop or ice crystal remains. This replicator is designed specifically to fit into a PMS* type canister with a sample arm projecting into the free air stream. Special features of the replicator are:

a) In-flight viewing capabilities of the replica about 15 seconds after collection. This is achieved by a closed circuit TV system. Field of view of the screen is 5 mm.
b) Variable speed film transport enabling high concentration of cloud particles to be spread such that probability of double impaction is small. Film speeds of .12, .25, .50, 1.0, 2.0 cm s^{-1} can be preselected for different flight conditions.
c) 200 feet of film to give up to 13.5 hours of operation in cloud.
d) Stop-Start during flight. If it is necessary to wait in the air for a cloud to develop, the replicator can be shut down and restarted.

The replica can be monitored by a standard TV system in flight to provide information on the type of cloud being penetrated. The replica can be analyzed on return by standard optical or electron microscopy; software is currently being developed under a NASA grant to provide digitized images of the replica for semi-automated analysis. The replica can be doped with materials to give a chemical identification on return to the laboratory (Oraltay, et al, 1992). Figure 1 shows a schematic of the mechanical system; figures 2 and 3 show examples of collected particles. Appendix A gives analysis of data collected by replicator during DC-8 flights in TOGA-COARE.

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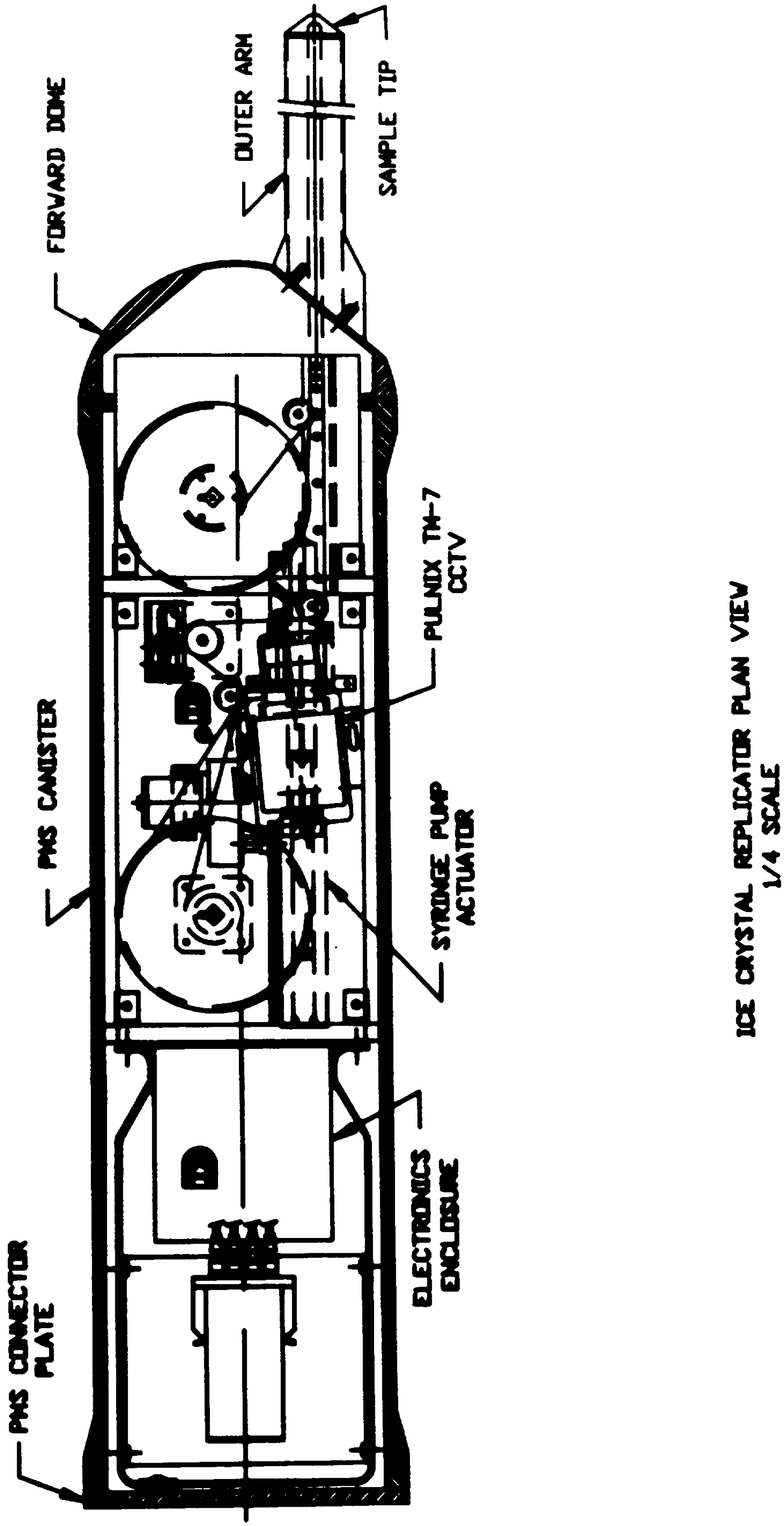

Figure 1: Ice Crystal Replicator plan view - 1/4 Scale

Figure 2. High magnification of small cirrus crystals, showing triangular plates, hexagonal plates, a thin needle and irregular, near spherical particles present in the same air parcel. Colors show replica and crystal thickness.

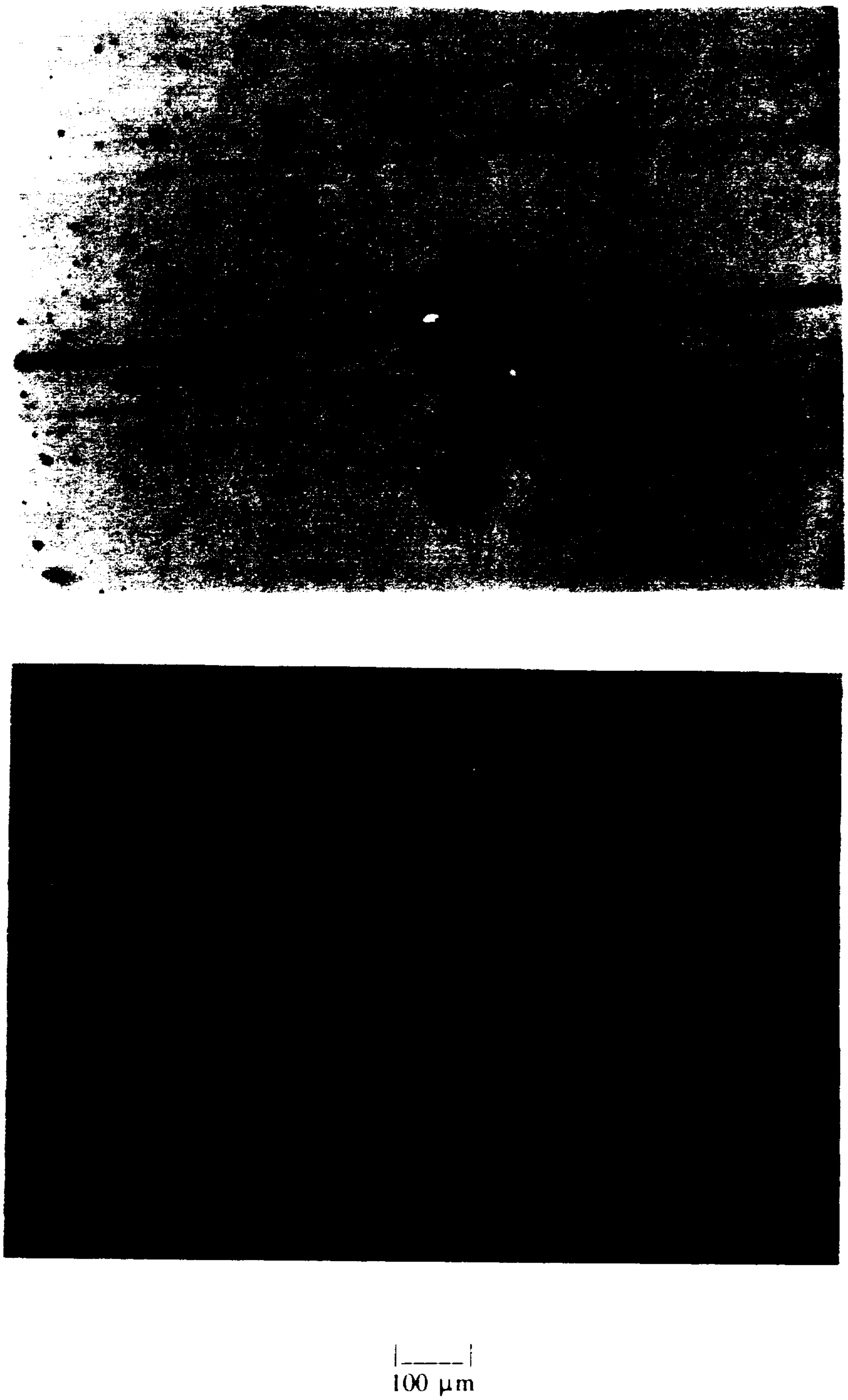

Figure 3. Replica of a poly-crystal showing growth as plates indicating appreciable subwater saturation conditions.

2. Modifications in Detail

2a. Formvar Pump

The existing gear pump was replaced with a syringe pump. Initial installation used a Monoject plastic syringe of 12 ml capacity. Subsequently a deterioration in the uniformity of the formvar coating was noted. The cause was unknown but was originally thought to be a contamination problem with the 16mm film or the formvar. It is now thought that the lubricant used by the Monoject manufacturer is the problem; they provided instructions for removing the lubricant but did not recommend it because excessive friction could result.

Alternate syringes were not available in the original size so 10 ml units were selected. Two were chosen to evaluate: an all plastic unit that was not lubricated and a glass syringe that is lubricated. The former was rejected due to high actuation forces. The latter is made by Becton, Dickinson and Co., B-D Glasspak, part number 5294. This has proven satisfactory in room temperature and freezer tests (-25C); the quality of the formvar coating has been good. A problem has been its reduced capacity, but if fully filled it contains just enough formvar for a full flight. The syringe mounting spring anchors were also changed for easier installation and removal. To accommodate the glass syringe the slot in the mounting block that accepts the flange on the plunger end of the syringe was widened from 2mm to 3mm. It is recommended that a new syringe be used for each flight.

2.b Heated Tip Roller

Although the sample inlet is heated, the tip roller is not. This can allow ice and/or water to accumulate during ascent to operating altitude. This can prevent proper film advance and block the sample inlet. A redesigned tip roller with an embedded 220 ohm heater was installed. Heater power is limited by a 50 ohm series resistor on the instrument main plate. If more heat is required at the tip, the series resistor can be reduced or removed; use the lowest power setting that is effective. The roller heater can be disabled by a toggle switch on the control box. It should be switched off when sampling to prevent premature formvar drying or ice crystal melting. The heater has a fairly high power density and should not be run a room temperature except for short tests, i.e. less than two minutes.

A pressure switch was also installed that can disable the roller heater without operator intervention. The switch is adjustable and is currently set to open at 28 kft. It is physically mounted to the instruments main plate but has not been wired into the heater circuit.

2c. Film Speed

The control box has a toggle switch for selecting between two film speeds - low or high. A rotary switch was added within the instrument that allows the speed range to be preselected before flight. The options are:

rotary switch position	low (cm/sec)	high (cm/sec)	pump voltage
1	.12	.25	4.0/7.0
2	.25	.50	7.0/11.0
3	.50	1.0	11.0/18.0
4	1.0	2.0	18.0/25.0

The syringe pump voltages must be also be preset after the rotary switch has been positioned; two potentiometers are located near the rotary switch for this purpose. The above values are good starting points. In laboratory tests the syringe pump has worked for all speed ranges. These speeds allow operating times of one to thirteen hours. It is still possible to start and stop the film advance in flight. A copy of the above table was affixed to the instrument.

2d. Applicator Head

It was difficult to get a formvar coating that was uniform across its width; excess formvar would flow out of the first of three applicator holes. A small punch was used to deform the first hole and restrict its flow area; this noticeably improved the quality of the formvar coating.

2c. Display

The control box includes a liquid crystal display that indicates the amount of remaining film in tens of meters. It uses digital circuitry and the display does not perfectly match actual film usage since a standard frequency control crystal is used. With the addition of the new film speeds, the display was counting down too rapidly. The divide by logic was modified as was the initial span. The display now reaches zero when the film is expended. This is still somewhat approximate since the amount of usable film depends on how tightly the supply reel is wound and how much film is used during preflight set-up. The TV monitor should be watched towards the end of the reel and the instrument shut down to prevent formvar application in the absence of film.

2f. Weight and Power Requirements

Weight of ER-2 replicator in light weight housing = 7.2 Kg.

The housing and sample arm are suitable for high speed flight (subsonic). They could be lightened and power consumption could be reduced for slower speed flight, i.e. on UAV's.

Power Requirements - 28 VDC

Motors 2 @ 8W	=	16W
CCTV	=	3W
Lamp	=	2W
Electronics	=	15W
		36W Operation
CCTV heater	=	3W
Electronics	=	11W
Plate	=	11W
Arm	=	75W
Inlet	=	75W
Tip roller	=	4W
		179W Heaters
TOTAL		215W

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N D B

MEASUREMENTS OF ICE PARTICLES IN TROPICAL CIRRUS ANVILS: IMPORTANCE IN RADIATION BALANCE

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1. INTRODUCTION

Cirrus is important in the radiation balance of the global atmosphere, both at solar and thermal IR wavelength. In particular cirrus produced by deep convection over the oceans in the tropics may be critical in controlling processes whereby energy from warm tropical oceans is injected to different levels in the tropical atmosphere to subsequently influence not only tropical but mid latitude climate (Ramanathan and Collins, 1991). Details of the cloud composition may differentiate between a net cooling or warming at these levels (Liou, 1986). The cloud composition may change depending on the input of nuclei from volcanic or other sources (Sassen, 1992). Observations of cirrus during the FIRE II Project over Coffeyville, Kansas (Arnott, et al, 1994i) and by satellite demonstrate that cirrus, on occasion, is composed not only of larger particles with significant fall velocity (few hundred μm, ½ m s^{-1}) but much more numerous small particles, size 10 - 20 μm, with smallfall velocity (cm s^{-1}), which may sometimes dominate the radiation field. This is consistent with emissivity measurements (King et al, 1993). In the thermal IR, ice absorption is strong, so that ice particles only 10 μm thick are opaque, at some wavelengths; on the other hand at other wavelengths and in the visible, ice is only moderately to weakly absorbing. It follows that for strongly absorbing wavelenghts the average projected area of the ice particles is the important parameter; in weakly absorbing regions it is the volume (mass) of ice which is important. The shape of particles and also their internal structure may also have significant effect on their radiative properties (Liou, 1986, Arnott et al. 1994ii).

In order to access the role of cirrus in the radiation budget it is necessary to measure the distribution of ice particles sizes, shapes and concentrations in the regions of interest. A casual observation of any cirrus cloud shows that there is variability down to a scale of at least a few 10^{o} m; this is confirmed by radar and lidar remote sensing. Thus aircraft measurements designed to give insight into the spatial distribution of radiation properties of ice crystals must be capable of examination of concentration, size and shape over a distance ideally of 100 m or less and to detect particles down to a size below which radiative effects are no longer significant.

2. INSTRUMENTATION

Measurements were made during the TOGA COARE Project, using the NASA DC-8 aircraft, in flights over the W. Pacific Jan./Feb. 1993. In view of the importance of tropical cirrus in the radiation balance, these measurements were specifically designed to cover the range of particles important in the radiation balance with a sampling rate of each instrument of some liters per second. Larger particles (> 100 μm), were detected by the 2 DC PMS optical probe and smaller particles ≥ 5 μm by a formvar replicator which collected particles through a 3 mm slit in a plastic solution to leave permanent casts. In parallel, measurements, were made of total nuclei (CN by a TSI 3010 instrument), which detects particles down to < 0.01 μm; details of these measurements are being published elsewhere (Hudson et al 1995). Data is analyzed from a few seconds to 200 s of flight path representing ½ km and 20 km path lengths. This enables measurement of the lower concentration of larger particles to give more relevant statistical data.

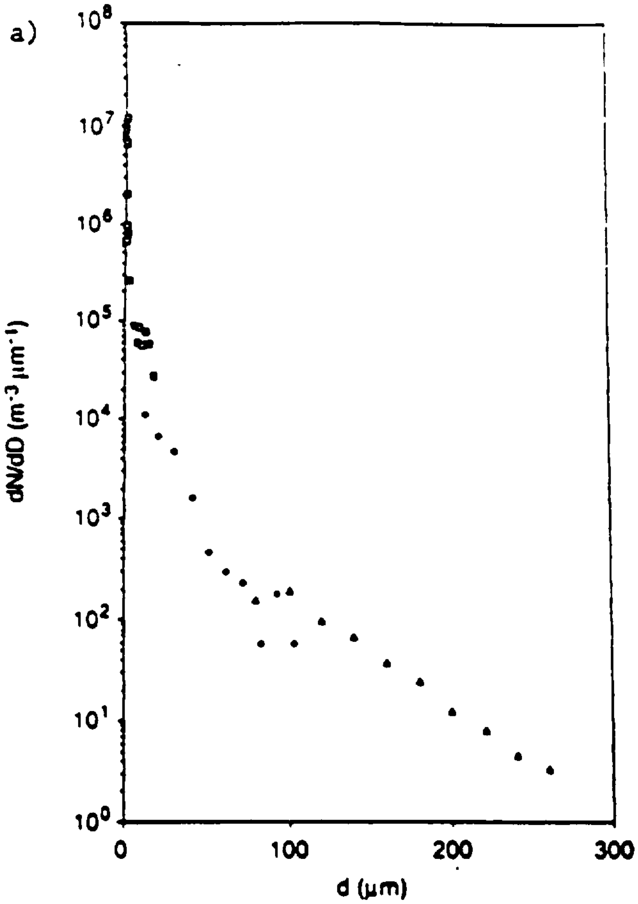
3. OBSERVATIONS

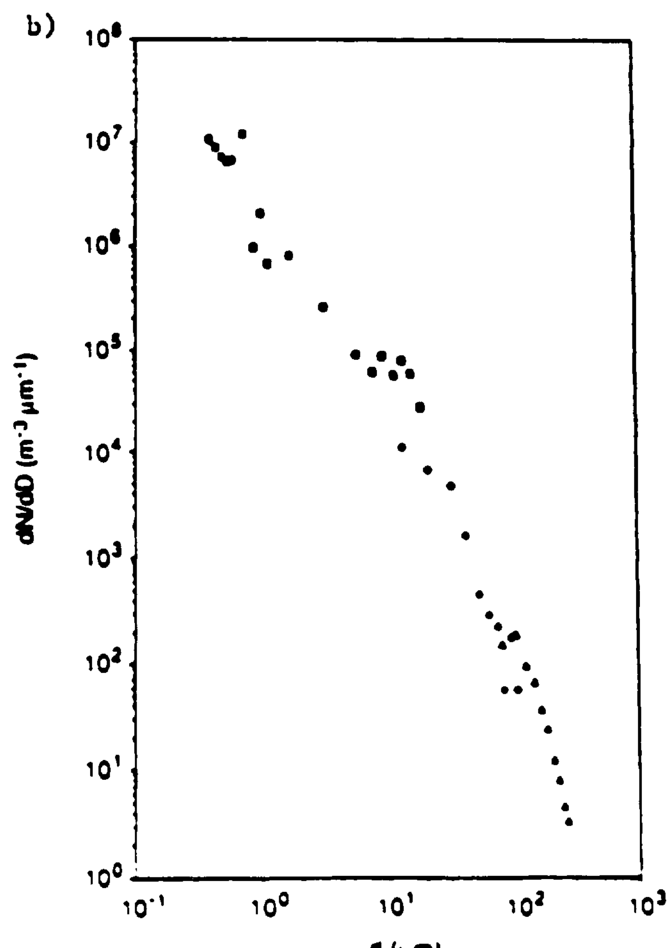
Deep cumulonimbus convective clouds grow, subject to local dynamical forcing, over the west Pacific warm pool to altitudes > 50,000 ft and top temperatures < -70°C. These clouds give ice anvil as they extend through the -40°C level which is spread away from the main vertical motion in winds prevailing aloft. Instrumentation was carried by the NASA-DC-8 which flew typically up to 42,000 ft with local air temperatures down to -55°C. Penetrations were made of anvils, not necessarily near the tops, which on occasion extended well above the highest flight level. Some penetrations were also made at lower levels. The data presented here were selected from flights where good quality replica and PMS data were collected. Initial analysis consists of size, habit, and concentration from PM 2DC images and from replica. Caveats in the data are that "null" images in the PMS (one pixel) need to be distinguished from noise, giving an effective lower limit for detection of two pixels, and of habit estimation of some 10 pixels in diameter. The replicator was mounted in a standard PMS pod and transported film at 2 cm s^{-1}, sampled through a 3 mm slot. Thus each 16 mm film frame collected crystals from a 200 m path. In principle, a "point" analysis of 3 mm of film gives a minimum resolution of 50 m. Sampling of particles; below a few μm size falls off because of reduced collection efficiency; particle "noise" in the solution and film also possesses problems of interpretation, for such small particles. Particles greater than a few 100 μm shatter on collection (which can be reconstructed); more serious is that they may shatter on entry into the slit itself. These fragmented particles can largely be excluded from analysis by a consideration of the concoidal fracture consistent with high speed impact of a brittle solid - as occurs in shatter of a glass window. In parallel with the ice measurements, data was obtained with a FSSP-300 X with 15 channels centered between 0.4 and 20 μm. The data from this type of instrument in ice is open to interpretation. Gardiner and Hallett (1985) showed that counting of supercooled cloud droplets in the presence of some ice particles was enhanced; the shape and internal structure of small ice particles has potential for influencing counts. Overall estimate is a potential for x 10 enhancement from replica from the conditions for shatter, and a comparable factor for FSSP total counts. A comparison of small particles by both techniques is made here, which give comparable results and some confidence in the measured concentrations.

4. RESULTS

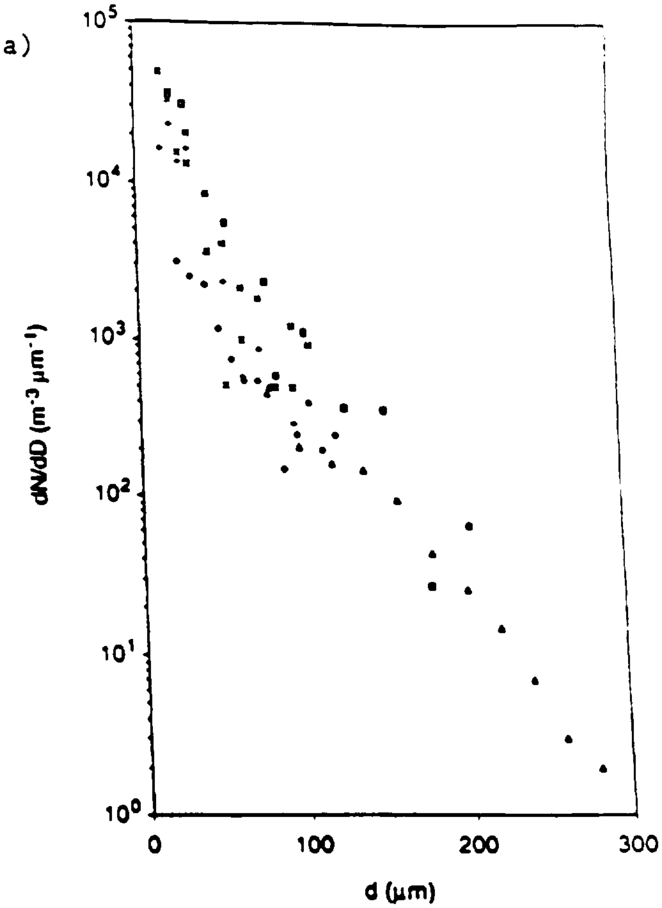
Measurements of replica, PMS - 2DC data, and FSSP data (Flight 12 only) are shown in composite plots at specific times and temperature. Data represent integration over about ½ minute, representing about 5 km of flight path. Fig. 1 shows data from an anvil at a temperature of -55°C. Replica and 2 D-C are in sufficient agreement on the region of overlap around 100 μm. It is noted that the concentration rises with decreasing size to the effective limit of replica analyzed - in this case about 10 μm. (The smaller crystals were examined using microscopy; the large ones by projection). The plot suggests a greater number than a straight line extrapolation log concentration plot of the larger size particles suggest. Composite data including PMS counts are shown in Fig. 2, which suggests even larger numbers at smaller size (nominally to 0.3 μm). The number concentration near 10 μm are consistent between FSSP and replica; there is also consistency in the overlap region between replica and 2D-C probe near 100 μm.

Anvil outflow from Hurricane Oliver; 17 11 52 - 17 12 34z. Flight 12, 6 Feb. 1993. Temperature -46°C. FSSP - replica overlap 10 - 20 µm. LAT: 11° 20 S. LONG: 155° 15 E. Squares are FSSP; others are replica.





Anvil from old convection, flight 15. Temperature -55°C. Time: 22 34 59 - 22 35 15z. 17 Feb. 1993. LAT: 40° 20; LONG: 155° 00 E. Replica and PMS - 2D data, effective overlap 75 - 200 µm. Replica and PMS data are consistent in overlap region. Squares are PMS 2D-C; others replica for various analyses.



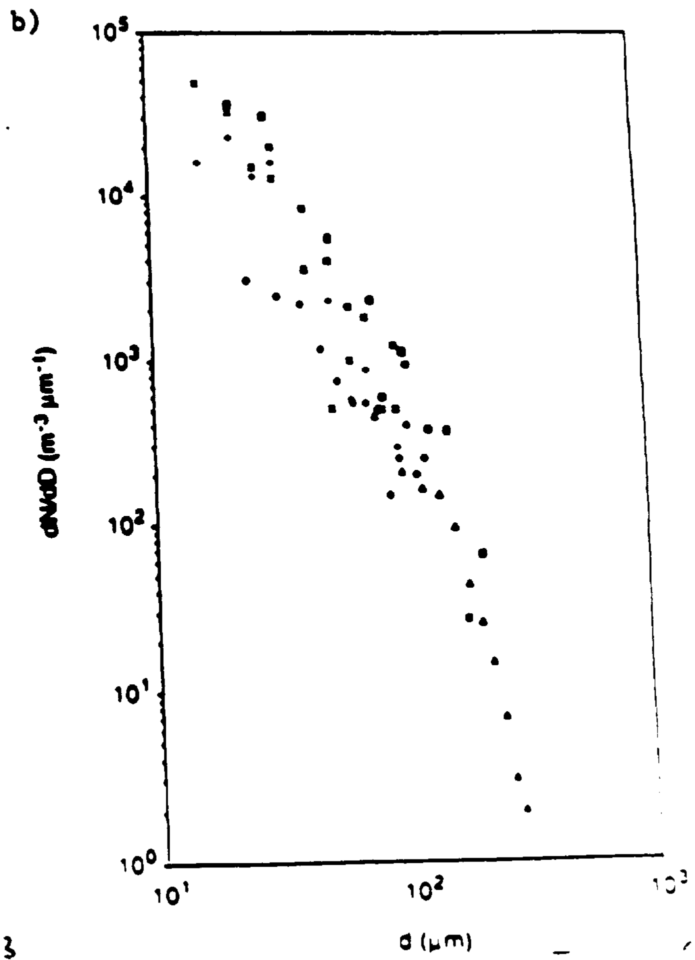


Figure 3 shows a composite data set of replica and 2D-C where consistency in counts occurs near 100 μm, but replica shows smaller numbers of particles larger than this size by a factor of about 5. Such discrepancy can be attributed to a more fragile structure of the large crystals, which break prior to replication observation of a large number of rejected shattered fragments are consistent with this possibility.

Figure 4a, b: shows a plot of area and volume (equivalent circle diameter) related to sizes suggesting a maximum contribution of particles 15 - 20 μm diameter, with a replica fall-off for large particles > 100 μm.

Neither PMS or replica showed any significant evidence for crystal aggregation at any level.

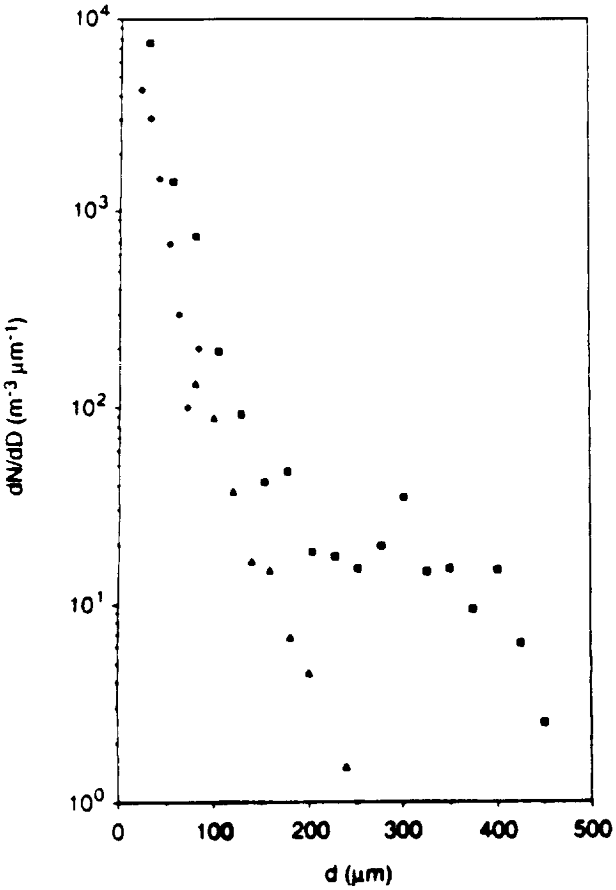


Figure 3: Anvil from old convection; descending cirrus plume. Flight 18; 24 Feb. 93. Temperature -28°C, 22 37 21 - 22 37 49z. Approx: LAT 151 LONG: 2° S. Replica and PMS 2DC effective overlap 75 - 200 μm. Replica gives fewer particles than PMS for size > 150 μm. Squares are PMS 2DC.

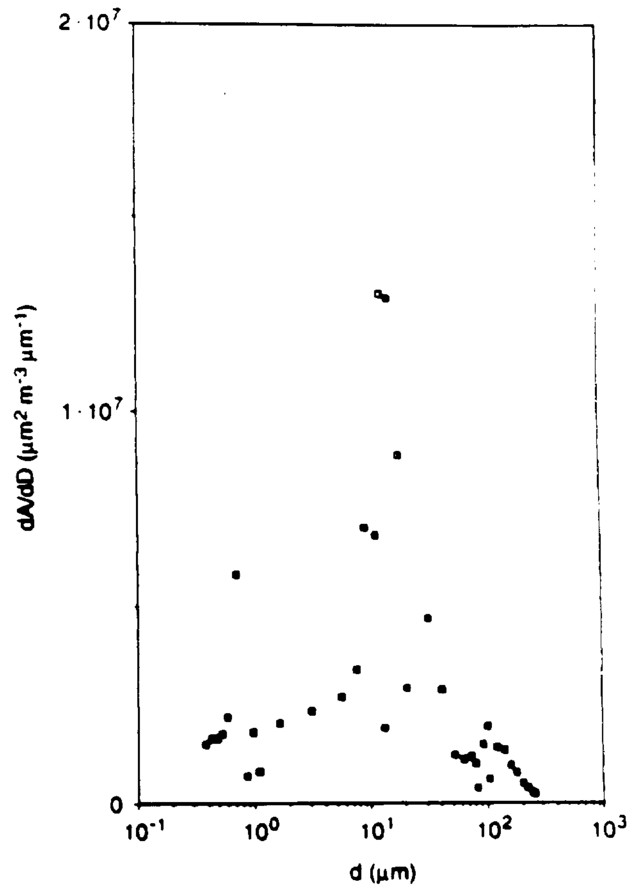


Figure 4a: Derived area of particles from in Fig. 2 from (flt 12) assuming an equivalent circle diameter. This data suggests a maximum area contribution for particles near 15 - 20 μm size.

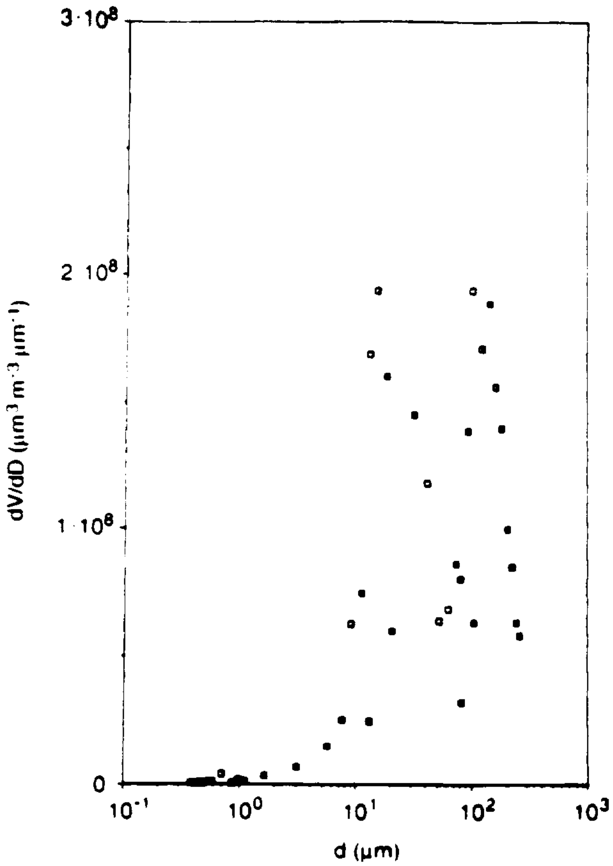


Figure 4b. Derived volume distribution showing a wide maximum contribution of particles 20 to 100 μm.

5. DISCUSSION

The most important result from these observations is the presence of large numbers of particles of size below 50 μm which contribute significantly to the effective surface area and opacity of the ice layer. It is important that the presence of the particles is shown in data obtained from two quite independent techniques - replicator and FSSP. It is to be noted that the numbers are well in excess (x 100) of those found by the ER2 at higher levels in the STEP Project (Knollenberg et al 1993) using a different FSSP with a much lower response to these sizes of particles. The presence of such particles is apparent in all 3 cases chosen for analysis, at temperatures -28, -45 and -55°C. In the former case, the penetration was through a descending region of ice from a higher layer aloft; this shows that such small particles are preserved in such weak vertical motions. It is of interest that CN measurements made during these flights, showed, on occasion, counts as high as 5,000 cm^{-3} (compared with "normal" background of a few hundred cm^{-3}). Volatility analysis in a controlled furnace showed that these particles evaporated near 120°C, strongly suggesting that their composition was sulfuric acid. Such numbers are consistent with observations of Clarke (1993). The ice particle concentration at the smallest size examined is a few cm^{-3}, indicating that only a fraction of the aerosol is activated to become ice particles. This implies that there could be present in the cirrus, in addition to the small ice particles, even larger number of inactivated sulfuric acid haze particles. Should the region of air containing such particles be subsequently lifted, further activation and freezing could ensue as particles dilute and freeze homogeneously. The origin of the initially large ice concentration is of interest. Qualitatively, a significant parameter is the temperature at which condensation begins on any aerosol present. Cloud bases of deep convection are at temperatures well above +20°C, so that the initial droplet spectrum is formed by the usual competitive process at these levels, controlled by the surface CCN spectrum and cloud base updraft. Much happens before these particles reach higher colder levels where ice nucleation begins - warm rain removes much water substance, nuclei are scavenged by various processes and incorporated by mixing from higher levels as the cloud builds upwards. The ultimate ice concentration, as homogeneous nucleation takes over after passing -40°C, can be envisioned to result from an identical competitive process whereby nuclei are diluted and frozen homogeneously, depending again on the tail of the CCN spectrum and vertical velocity. A knowledge of the complete cloud properties (CN, CCN, vertical velocity), it is vital in understanding the ice origin. The origin of the nuclei ALOFT can be speculated to be possibly from the surface - advected in strong convection, and possibly from moderate volcanic activity which is always going on in the W. Pacific. The relative role of volcanic and ocean production is an area for potentially fruitful speculation.

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a) b) c) d)

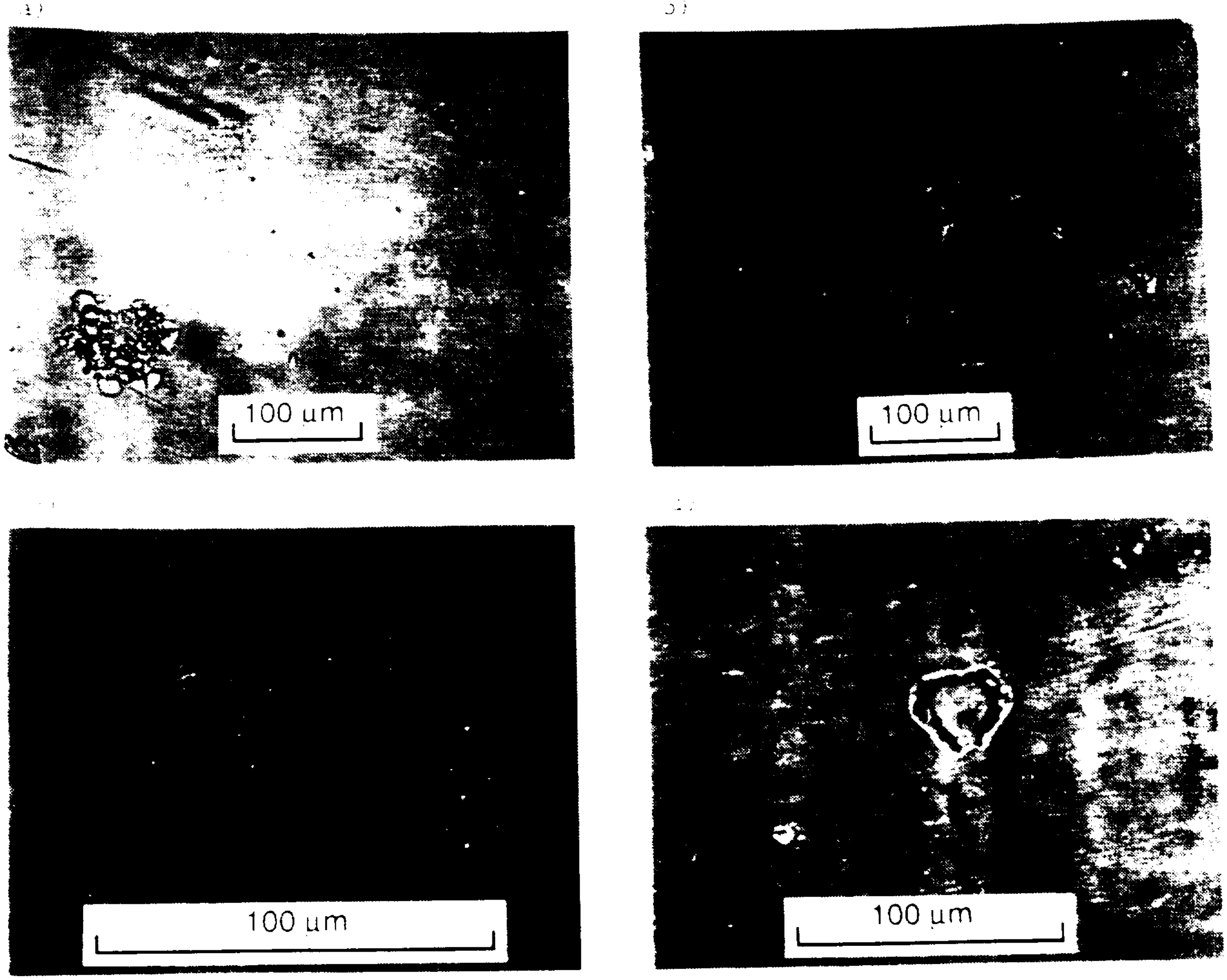

Figure 5. Examples of Formvar replicas: a) partly fragmented polycrystals showing crystals with hexagonal periphery; b) hexagonal plate with shatter fragments from other crystals (these would not be counted as individual crystals); c) columns, partly shattered on impact; d) crystal showing trigonal symmetry.

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